A STUDY OF MODELS FOR OPTIMUM ASSIGNMENT OF MANPOWER TO WEAVING OPERATIONS

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A STUDY OF MODELS FOR OPTIMUM

ASSIGNMENT OF MANPOWER TO WEAVING OPERATIONS

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Dedication

......TO MY WONDERFUL WIFE AND SON WHOM I LOVE.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The aim of this thesis is to study mathematical models for determination of optimum levels of service to be provided in a weave room. The models will identify and account for the major costs of weaving, including costs of labor, material, and lost production.

An attempt will be made to show how the optimal loom assignment may be used effectively so as to minimize costs. Although some work has been carried out in general areas of assigning machines to operators, within the textile industry only a little research has been done.

The production efficiency of any weaving mill depends mainly on the quality of services provided in that mill. High efficiency is due to good and reliable service levels. This service costs money, and the less the amount of money spent for a good quality of service, the more money saved for other financial purposes of the mill.

When weavers service looms, they represent a cost and so do the looms that are waiting to be serviced by the weavers. Having many weavers implies high costs from the wasteful use of weavers. Having very few weavers also implies high costs from the excessive loom waiting time, this cost being due to the cost of lost production. A rational means, therefore, to determine the number of weavers to provide in a weave room is to be determined. This means will be based on models incorporating the costs of labor and lost production.

The number of weavers necessary to keep the production at a desired level, depends on how often the loom stops. If too many weavers are utilized, then there will be an excessive weaver's idle time; however, if not enough weavers are utilized then extra loom downtime will occur. A balance between these two levels such as point "A" in Figure 1, is the optimal point at which costs are minimum.

Purpose of Study

Many weaving mills may face losses or fail to attain maximum possible profit because of the lost productivity due to the improper assignment of looms to weavers.

Traditionally, the amount of labor assigned to weaving has been based on the rate of loom stops. Sufficient labor is usually supplied to keep the loom downtime to a minimum.

The models in this study will be based on all costs that affect the weaving process. The function describing each class of costs is validated with data obtained from a typical weave room. Time and motion studies will be made and other data obtained to determine the values for parameters included in the models.

The cost of waiting time often represents a difficulty, since it represents productive time lost through an avoidable cause. If there are no repercussions on sales, dealer relations or the like, this cost may be assumed to be equal to the volume of the lost output. If there are external effects, these must be accounted for in assigning a value of the waiting time [1].

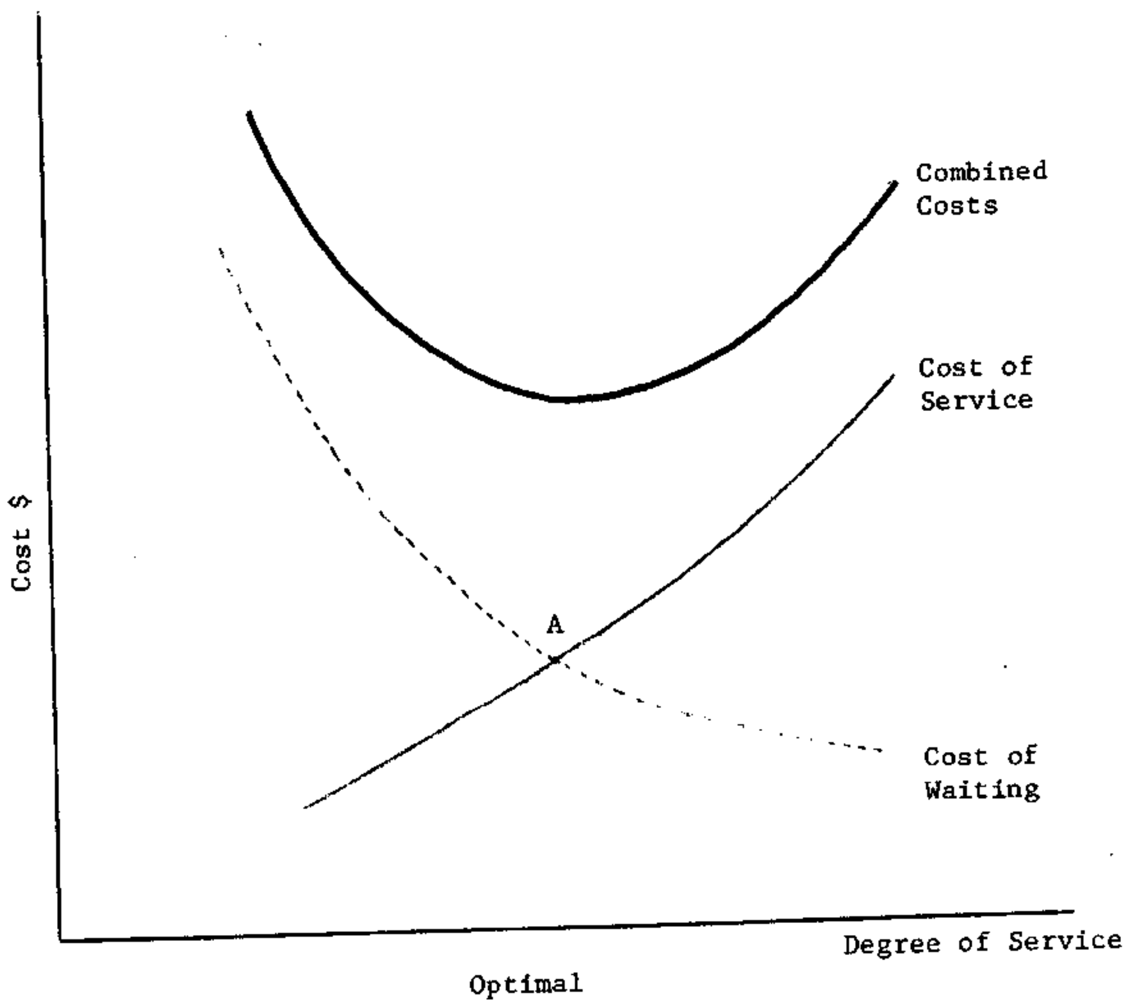

Figure 1. Costs vs. the Degree of Service

It is obvious that mills will be able to minimize costs and consequently maximize profits through economic considerations of work load assignments.

This thesis attempts to present reasonable models that could be used in assigning looms to weavers in order to minimize costs incurred.

Method of Study

In the work to follow, several methods of assigning looms to weavers will be discussed. These methods could be used by any weaving mill regardless of the type or number of looms in production. The data used were collected from a typical weave room [2] by time study carried out in the weave room.

The jobs that the weaver does need certain times to be performed. The times required for carrying out these jobs are determined, and all times for the various elements are measured with the aid of a stop watch. When each time is recorded, the weaver is rated with respect to speed for the job he performed. The rating is given by using a standard rating system. The standard rating is the rating at which a skilled weaver will do the same job at a normal pace. The basic time is found by multiplying the observed time by a factor. This factor is the ratio of the observed rating to the standard rating [3], as follows:

$$\text{Basic time} = \text{Observed time} \times \frac{\text{Observed rating}}{\text{Standard rating}}$$

These observations are repeated several times, and the average basic time is obtained, the average basic time is then used to calculate the optimum number of looms to assign to a weaver.

CHAPTER II

FACTORS AFFECTING LOOM ASSIGNMENTS

Loom Idle Time

When a certain number of similar production looms are assigned to a weaver in any weave room, these looms are likely to stop from time to time. Loom stops are caused by many factors such as warp breakage or filling yarn tangles. The loom will not continue production until it is serviced by the weaver [4]. When more than one loom stops at the same time, then the weaver can only service one loom at once, while the other looms wait until the weaver tends them and puts them into production. During this waiting period, production is lost. If a weaver has set of N looms weaving the same fabric, then the effect of looms stopping independently of each other, can be illustrated in Figure 2.

If a number of stopped looms per weaver's set is S at some instant, then there are only (N-S) looms remaining running in his set of looms. The rate of production per loom and per weaver is a function of the rate of the loom stoppages, service time (the time the weaver is tending the loom, checking it, and putting it back into production), and the time the looms wait for service. Production is lost during two periods of time, the first period being the loom is stopped and the weaver is tending it such as periods T_{s_1} and T_{s_2}, and the second period of time being the period during which the loom is stopped and the weaver is not tending it, such as period T_q.

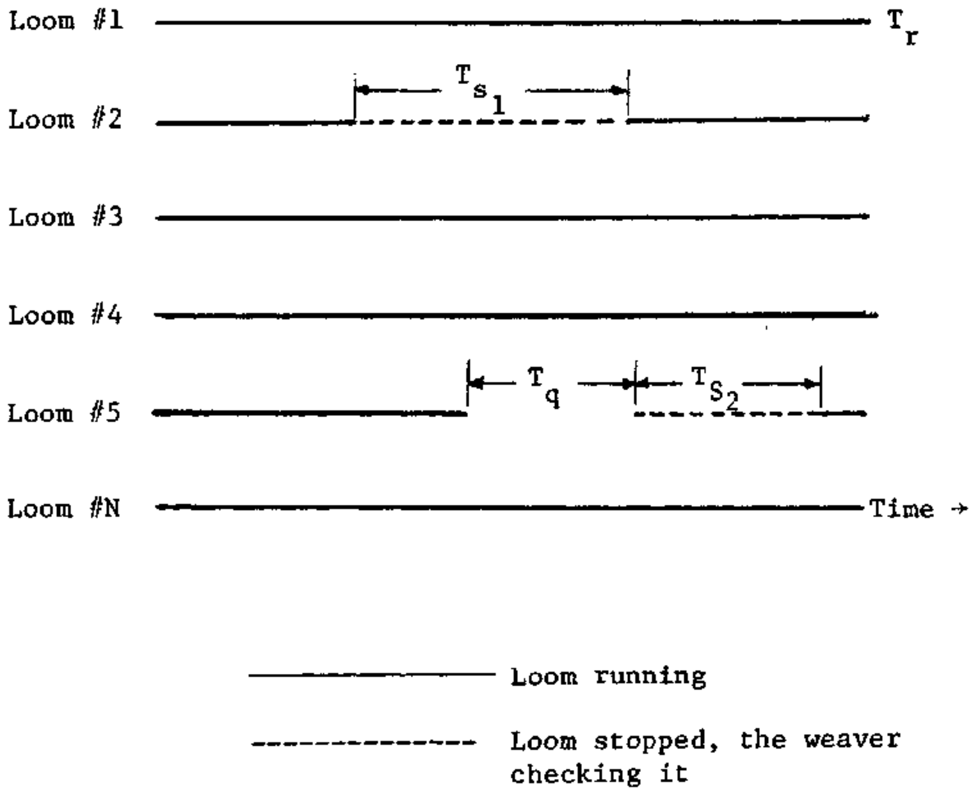

Figure 2. Loom Interference

Loom Stoppages

The weaver's working time per unit of output is based on the frequency of the different operations, e.g. repairing a warp or filling break, multiplied by the average working time per operation. To this time must be added the time required for ancillary duties, and also that taken up by patrolling.

Since looms do not run at 100% efficiency, the time required to produce a certain quantity of fabric can be classified in three ways: the loom running time, the time the loom is stopped waiting for repairs, and the time the weaver spends repairing the loom. To determine the number of looms to assign to a weaver, the following information should be considered:

(1) The frequency of warp and filling breakages, and the mechanical stoppages occuring per unit of time or per unit of output.

(2) The average time required for the weaver to remedy the problems in (1).

(3) Time required for supervision and patrolling.

(4) Time required for ancillary duties.

(5) Net time the weaver is available for work.

(6) Time the loom waits for service.

An exact record of the number of end breakages, broken picks, and mechanical stoppage is not only an indispensable prerequisite for calculating the work load of the weaver, but also forms the basis for increasing the loom efficiency and for improving the quality of fabric. It is necessary to take as well the reasons for these stoppages. Efforts must be made to increase productivity without increasing the work load, which could be achieved by reducing the number of loom stoppages. The main reason for loom stoppages in many cases is not to be found in the weaving department itself, but in the preliminary stages of processing, such as winding, warping and slashing [5].

For achieving highest production in the weave room, a close co-operation between the different departments is necessary. In addition to representing a loss of time, loom stoppages also decrease the quality of the fabric. Care in spinning, winding, warping, slashing and drawing-in always pays off in the weaving operation. Loom stoppages should be reported by people of enough knowledge of processes prior to weaving, so as to be able to give a reliable estimate of the reasons for these stoppages. The weaver should be told loom stoppages affect productivity.

When a weaver stops the loom to clean the warp for instance, it does not count as a stoppage, but it is considered when calculating the work load and is treated as miscellaneous loom tending. End breakages should be checked whether the breakage occurred in the front of the loom or at the back of the loom, that is whether it is in the reed or in the harness. It is also important to note whether the break is a multiple breakage or whether is is the warp stop motion which stopped the loom without any breakages, that is by loose ends or fluff in the drop wire. In this case, only the warp has to be in order for restarting the loom. A subdivision of these breakages is necessary because the working time per operation depends on the position and the kind of breakage. When an end breakage occurs at the back of the loom, it takes more time to remedy than that breakage occurring at the front. Table 1 shows a subdivision of these breakages.

Walking Time

With large loom allocations, which are achieved by many mills using automatic looms, the walking time of the weaver is an important factor in relation to the work load.

The weaver usually can tend looms in two different ways: individually or in sequence. When tending looms individually and one or more looms are idle, the weaver goes by the shortest distance from his present location to the idle loom nearest him. When working in sequence, the weaver goes from one loom to another along a prescribed route, restarting all idle looms. The latter method is useful only if the looms and the fabrics are inspected as the weaver goes from one loom to another. Both methods of working have advantages and disadvantages. When going to the loom individually, the loom waiting times are reduced to a minimum which maximizes the efficiency, but the weaver on his way cannot do any important inspection. With the system of going to the loom in sequence, the walking time per stoppage is naturally much higher, as the weaver does not go to the idle loom by the quickest route, the loom waiting times are thus increased, and the efficiency is lower. On the other hand, the weaver can inspect other looms while following this system.

Table 1. Types of Loom Stoppages

Warp Breaks	Filling Breaks	Mechanical Breaks
Break in dropwires	Bad quill or bobbin	Shuttle not in box
Break in heddles	Tail	Feeler trouble
Break in reed	Trash	Break at change
Break in warp	Miss picks	Stop on change
Break in selvage	Break in shuttle	Loom repairs
Tie back-body	Cut by feeler	Cleaning
Entangled yarn	Break in shuttle box	Filling change
Slubs loose on yarn	Slub	Stop motion
Crossed ends	Knots in filling	Others
Lost ends	Sloughed off	
Extra ends	Bad filling	
Hard size	Others	
Cut by shuttle		
Slack ends		
Others		

CHAPTER III

METHODS OF LOOM ASSIGNMENTS

Case I: General Loom Assignment Method

Definition of the Operation, Fabric (i)

The data used in the following analysis were obtained from a typical weave room [2], and by personal contacts [7]. The fabrics studied are cotton fabrics. The production specifications of fabric (i), are as illustrated in Fabric (i), cost sheet, Table 2 [8]. The costs shown are not actual costs from a mill but are presented as illustrative data. The production in yards of fabric (i), per loom per week,* is:

$$= \frac{187 \times 40 \times 60 \times 96}{36 \times 60 \times 100}$$

$$= 199.47$$

Table 3 shows hypothetical but realistic loom stoppage data, and the frequencies of these stoppages per loom per week.

As it has been stated earlier, the working hours per week are 40 hours (2400 minutes). Allowing 90% occupied time, and 580 minutes per week for patrolling and other miscellaneous duties, the net working time per loom per week is:

---

*The working hours per week were assumed to be 40 hours.

Table 2. Fabric (i) Cost Sheet

Width: 40" Construction: 64x60 Yards per Pound: 5.43 No. Beams: 1
Loom Used: 44" x 2 Dr. Speed: 178 ppm % Production: 96
Yards per Loom Week: 199.47 Reed Width: 42.75" Ends per dent-body: 1
Selv. 1 Number of Loom Producing Fabric (i) = 250 No. Harness: 2
Style No. 1
Fabric: print cloth
Date: Jan. 11, 1978

Yarn	Twist Mult.	Ends or Picks	Lbs. Per Yard	Manufacturing Cost Per Yd. of Cloth		
				Overhead	Labor	Total
W 30	4.25	2528	0.1058	0.01731	0.02739	0.04470
W 30/2	4.25	16	0.0014	0.00027	0.00060	0.00087
F 46	3.90	60	0.0664	0.01500	0.01992	0.03492
Warp & Filling	Total	2604	0.1736	0.03258	0.04791	0.08049
Starch Weight	10%		0.0107	0.00006	0.00012	0.00018
Total Weight			0.1843			
Slashing				0.00330	0.00300	0.00630
Warp Drawing and Typing				0.00015	0.00070	0.00085
Weaving					0.00900	0.00900
Battery Hands					0.00450	0.00450
Fixers					0.01200	0.01200
Weaving Expense				0.02400	0.01500	0.03900
Cloth Room				0.00150	0.00600	0.00750
Overtime & Vacation Pay 3.6%					0.00360	0.00360
Total Manufacturing Cost				0.09595	0.14599	0.24194
Starch Cost						0.00406
Packing Materials						0.00034
Total Warp and Filling Stock						0.10068
Total Mill Cost						0.34753
Selling Expense (4%)						0.01390
Total Cost Per Yard of Cloth						0.36143
Profit Per Yard (15%)						0.05420
Total Selling Price						$0.42000

Table 3. Loom Stoppages and Their Frequencies, Fabric (i)

No.	Duty	Repeats per 40 hrs.	Serivce Time, Min.	Total Service Time Min. per 40 hrs.
1	Repair warp stops	11.20	0.995	11.14
2	Repair filling breaks	36.80	0.655	24.10
3	Mech. and Miscellaneous stops	8.40	0.405	3.40
4	Marking loom number on loom board	0.21	2.728	0.57
5	Marking loom number on smash board	0.21	2.728	0.57
6	Cleaning reed cap and shuttle guard	1.67	0.588	0.98
7	Cleaning filling fork well	1.67	0.500	0.84
	TOTAL			41.60

$$(2400 \times 0.90) - 580 = 1580 \text{ minutes}$$

The average number of looms N to assign to a weaver, is calculated as the ratio of the net working time per loom per week to the total stoppage time per loom per week, that is:

$$N = \frac{1580}{41.60} = 37.98$$

that is 38 looms are assigned to each weaver on the average. Therefore, the number of weavers required for the 250 looms is,

$$W = \frac{250}{38} = 6.58$$

that is 7 weavers are required to take care of the 250 looms. The 250 looms may be assigned to the 7 weavers as follows:

Weaver	Looms Per Weaver
1	36
2	36
3	36
4	36
5	36
6	35
7	35

Calculation of the Total Cost Per Week, Fabric (i)

The cost considered here is the cost of the lost production due to loom stops, assuming that the loom is serviced as soon as it stops. The cost of lost production due to loom interference is not considered but is taken into account later in this analysis.

From Table 3, the time lost in minutes per loom per week consists of the following:

1.	Warp stop repair	11.14
2.	Filling break repair	24.10
3.	Mechanical and miscellaneous stops	3.40
4.	Stops due to other reasons*	2.96
	TOTAL:	41.60

The cost of lost production** per week, is calculated as follows: From Table 2, the profit per yard of fabric (i) is 6¢. The production in yards of fabric (i) per loom per hour is:

$$= \frac{199.47}{40}$$

$$= 4.99$$

From Table 3, the loom is stopped for 41.60 minutes per week. The cost of the lost production during this period of fabric (i) is calculated as follows:

---

*Stops such as cleaning the reed cap, and shuttle guard.

**The lost production calculated for fabric (i) is only for the case considered. It is based on the data from Table 3; the production loss, therefore, will vary according to the rate of stoppage of the loom under study.

$$= \frac{41.60 \times 4.99 \times 250 \times \$0.06}{60}$$

$$= \$51.90$$

The base pay of the weavers per hour: $2.50

Total base pay of the weavers per week: $7 \times \$2.50 \times 40 = \$700.00$

The variable cost per week is calculated as follows:

$$C_v = \frac{187 \times (2400 - 41.60) \times 250 \times \$0.4100}{100,000}$$

$$C_v = \$452.05$$

The total cost per week:

C_t = Base pay of weavers per week + the variable cost per week + the cost of lost production per week

$$C_t = \$700.00 + \$452.05 + \$51.90$$

$$C_t = \$1203.95$$

Fabric (ii)

The data for fabric (ii) were obtained from the same source stated in fabric (i). The production specifications of fabric (ii) are illustrated in the detailed fabric cost sheet in Table 4. The production in yards per loom per week (40 hrs.) of fabric (ii), is:

$$= \frac{187 \times 40 \times 60 \times 95}{36 \times 80 \times 100} = 149.60$$

Table 5 represents the loom stoppages and their frequencies per loom per week.

Again, as it has been stated in fabric (i), the net working time per loom per week is 1580 minutes. The average number of looms N to assign to a weaver is calculated as the ratio of the net working time per loom per week to the total stoppage time per loom per week [7]; that is,

$$N = \frac{1580}{52.05} = 30.36$$

That is, 31 looms are assigned to each weaver on the average; therefore, the number of weavers required for 250 looms is:

$$W = \frac{250}{31} = 8.06$$

That is, 8 weavers are required to take care of 250 looms. The 250 looms may be assigned to these 8 weavers as follows:

Weaver	Looms Per Weaver
1	31
2	31
3	31
4	31
5	31
6	31
7	32
8	32

Table 4. Fabric (ii) Cost Sheet

Width: 39" Construction: 80x80 Yards per Pound: 4.00 No. Beams: 1
Loom Used: 44" x 2 Dr. Speed: 187 ppm % Production: 96
Yards per Loom Week (40 hrs): 149.60 Reed Width: 41.75" Ends per dent-body: 1
Selv. 1 Number of Looms Producing Fabric (ii) = 250 No. Harness: 2
Style No. 2
Fabric: print cloth
Date: Jan. 11, 1978

Yarn	Twist Mult.	Ends or Picks	Lbs. Per Yard	Manufacturing Cost Per Yd. of Cloth		
				Overhead	Labor	Total
W 30	4.25	3088	0.1355	0.02146	0.03390	0.05536
W 30/2	4.25	16	0.0014	0.00026	0.00060	0.00086
F 40	3.90	80	0.0994	0.01800	0.02500	0.04300
Warp and Filling Total			0.2363	0.03972	0.05950	0.09922
Starch Weight	10%		0.0137	0.00006	0.00010	0.00016
Total Weight			0.2500			
Slashing				0.00330	0.00300	0.00630
Warp Drawing				0.00015	0.00070	0.00385
Weaving					0.00900	0.00900
Battery Hands					0.00450	0.00450
Fixers					0.01200	0.01200
Weaving Expense				0.02400	0.01500	0.03900
Cloth Room				0.00150	0.00600	0.00750
Overtime & Vacation Pay 3.6%					0.00360	0.00360
Total Manufacturing Cost				0.07079	0.11772	0.19851
Packing Material Cost						0.00120
Starch Cost						0.00521
Total Warp & Filling Stock						0.13705
Total Mill Cost						0.59709
Selling Expense 4%						0.02390
Total Cost Per Yard of Cloth						0.61099
Profit Per Yard 15%						0.09160
Total Selling Price						0.70259
Total Selling Price Rounded						$0.71000

Table 5. Loom Stoppages and Their Frequencies, Fabric (ii)

No.	Duty	Repeats per 40 hrs.	Service Time, Min.	Total Service Time Min. per 40 hrs.
1	Repair warp stops	15.18	0.995	15.10
2	Repair filling breaks	44.50	0.655	29.15
3	Mech. and Miscellaneous stops	10.03	0.405	4.06
4	Marking loom number on loom board	0.30	2.728	0.82
5	Marking loom number on smash board	0.30	2.728	0.82
6	Cleaning reed cap and shuttle guard	2.04	0.588	1.20
7	Cleaning fork well	1.80	0.500	0.90
	TOTAL			52.05

Calculation of the Total Cost Per Week, Fabric (ii)

The cost considered here is the cost of the lost production due to loom stops, assuming that the loom is serviced as soon as it stops. The cost of lost production due to loom intereference is not considered but is taken into account later in this analysis.

From Table 5, the time lost in minutes per loom per week consists of the following:

1.	Warp stop repair	15.10
2.	Filling break repair	29.15
3.	Mechanical and miscellaneous stops	4.06
4.	Stops due to other reasons	3.74
	TOTAL:	52.05

The cost of lost production per week is calculated as follows: From Table 4, the profit per yard of fabric (ii) is 9¢. The production in yards of fabric (ii) per loom per hour is:

$$= \frac{149.60}{40}$$

$$= 3.74$$

From Table 5, the loom is stopped for 52.05 minutes per week. The cost of the lost production during this period of fabric (ii) is calculated as follows:

$$= \frac{52.05 \times 3.74 \times 250 \times \$0.09}{60}$$

$$= \$73.00$$

The base pay of the weavers per hour: \$2.50

The total base pay of the weavers per week:
8 x \$2.50 x 40 = \$800.00

The variable cost per week is calculated as follows:

$$C_v = \frac{187 \times (2400 - 52.05) \times 250 \times \$0.4100}{100,00}$$

$$C_v = \$450.04$$

The total cost per week

C_t = Base pay of weavers per week + the variable cost per week + the cost of lost production per week.

$$C_t = \$1323.04$$

CHAPTER IV

CASE II: CONSIDERATION OF LOOM INTERFERENCE

Work Measurement of Multimachine Assignments

A multimachine assignment is one where more than one machine is operated or tended by a single operator or operator-helper team working together. The solution to many multimachine assignments involves the calculation of machine interference idleness and operator idleness which are caused by assigning more than one machine to a single operator. Machine interference idleness is the time that a machine is idle because the operator is serving another machine in the group. Operator idleness is the time that the operator is idle because all the machines in the groups are running automatically [9].

Two general types of solutions to multimachine assignment problems could be used, depending on whether machines are randomly serviced or systematically serviced by the operator. Looms are examples of machines that have random servicing demands. In the case of weaving with looms, the occurrence of yarn breakage, and therefore loom stoppage, is entirely random. Solutions based on the laws of probability are used for these assignments.

The efficiency of a machine individually tended by one operator is obviously unity minus the portion of time the machine is not in production.

Table 6 shows average percent (of elapsed time) interference

Table 6. Random Machine Interference Table*

No. machs.	Operator's total percent interference-causing work load† on individual attention basis														
	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
2	3.9 52	4.9 48	5.9 44	7.0 40	8.2 36	9.5 32	10.7 29	12.4 25	13.9 23	15.5 18	17.3 17	18.8 15	20.8 13	22.6 11	24.4 9
3	3.7 52	4.7 48	5.7 43	6.7 39	7.8 35	9.2 32	10.5 28	12.2 25	13.8 22	15.4 18	17.2 17	18.8 15	20.8 13	22.6 11	24.4 9
4	3.2 32	3.9 47	4.9 43	5.8 39	6.9 35	8.2 31	9.4 28	10.9 24	12.6 21	14.2 18	15.9 16	17.7 14	19.6 12	21.6 10	23.5 8
5	2.7 52	3.5 47	4.3 43	5.2 39	6.2 34	7.3 31	8.6 27	9.9 23	11.4 20	13.0 17	14.7 15	16.5 12	18.5 11	20.6 8	22.6 7
6	2.3 51	3.1 47	3.7 42	4.5 38	5.5 34	6.6 30	7.8 26	9.1 23	10.6 20	12.2 17	13.8 14	15.7 11	17.6 9	19.8 7	21.7 6
7	2.1 51	2.7 46	3.3 42	4.0 38	5.0 34	6.0 30	7.1 26	8.4 22	9.8 19	11.3 16	13.0 13	14.9 11	16.8 8	18.8 7	20.9 5
8	1.9 51	2.4 46	3.0 42	3.7 37	4.6 33	5.4 29	6.6 25	7.7 22	9.0 18	10.6 15	12.3 12	14.1 10	16.0 8	18.2 6	20.2 4
9	1.7 51	2.2 46	2.8 42	3.5 37	4.3 33	5.0 29	6.0 25	7.1 21	8.5 17	9.9 16	11.6 12	13.4 9	15.4 7	17.5 5	19.6 4
10	1.5 51	2.0 46	2.6 42	3.1 37	4.0 33	4.6 28	5.6 25	6.6 21	8.0 17	9.4 14	11.0 11	12.8 8	14.8 6	17.0 4	19.0 3
11	1.4 51	1.9 46	2.4 41	2.9 37	3.7 33	4.3 28	5.3 24	6.2 20	7.5 17	8.9 13	10.5 11	12.4 8	14.4 6	16.5 4	18.5 3
12	1.3 51	1.8 46	2.2 41	2.7 37	3.4 32	4.1 28	5.0 24	5.9 20	7.1 16	8.5 13	10.1 10	12.0 7	14.0 5	16.1 4	18.2 2
13	1.3 51	1.7 46	2.1 41	2.5 37	3.2 32	3.9 28	4.7 24	5.6 20	6.8 16	8.1 13	9.7 9	11.6 7	13.6 5	15.7 3	18.0 2
14	1.2 51	1.6 46	2.0 41	2.4 37	3.0 32	3.7 28	4.4 24	5.3 20	6.4 16	7.7 12	9.3 9	11.2 7	13.3 5	15.4 3	17.8 2
15	1.1 51	1.5 46	1.9 41	2.2 36	2.8 32	3.5 28	4.2 23	5.1 19	6.1 15	7.4 12	8.9 9	10.8 6	13.0 4	15.1 3	17.6 1
16	1.1 51	1.4 46	1.8 41	2.1 36	2.6 32	3.2 27	4.0 23	4.8 19	5.9 15	7.0 12	8.5 9	10.5 6	12.6 4	14.8 2	17.4 1
17	1.1 50	1.3 46	1.7 41	2.0 36	2.5 32	3.1 27	3.8 23	4.6 19	5.6 15	6.7 11	8.2 8	10.2 6	12.3 3	14.5 2	17.2 1
18	1.0 50	1.2 46	1.6 41	1.9 36	2.4 32	3.0 27	3.6 23	4.4 19	5.4 15	6.6 11	7.9 8	9.9 5	12.0 3	14.4 2	17.1 1
19	1.0 50	1.1 46	1.5 41	1.9 36	2.3 32	2.9 27	3.5 23	4.2 19	5.2 15	6.2 11	7.7 8	9.6 5	11.8 3	14.3 1	17.0 —
20	0.9 50	1.1 46	1.4 41	1.8 36	2.2 32	2.8 27	3.4 23	4.1 18	5.0 15	6.0 11	7.5 8	9.3 5	11.6 2	14.1 1	16.9 —
25	0.8 50	0.9 45	1.2 41	1.5 36	1.8 31	2.3 27	2.8 22	3.4 18	4.2 14	5.2 10	6.6 7	8.4 4	10.6 2	13.7 —	16.8 —
30	0.7 50	0.8 45	1.0 41	1.2 36	1.6 31	2.0 26	2.4 22	2.9 17	3.7 13	4.8 9	5.9 6	7.7 3	10.2 1	13.4 —	16.7 —
40	0.5 50	0.6 45	0.8 40	1.0 36	1.2 31	1.5 26	1.8 21	2.3 17	2.9 13	3.7 9	5.0 5	6.8 2	9.4 —	13.2 —	16.6 —
50	0.3 50	0.5 45	0.6 40	0.8 36	0.9 31	1.2 26	1.5 21	2.0 17	2.5 12	3.2 8	4.3 4	6.1 1	9.3 —	13.1 —	16.6 —
75	0.2 50	0.3 45	0.4 40	0.5 35	0.6 30	0.8 26	1.0 21	1.3 16	1.7 12	2.1 7	3.3 3	5.2 —	9.1 —	13.0 —	16.5 —
100	0.2 50	0.2 45	0.3 40	0.4 35	0.5 30	0.7 26	0.8 21	1.0 16	1.2 11	1.6 7	2.8 3	5.1 —	9.0 —	13.0 —	16.5 —

*Prepared by Dale Jones, Michigan State University, East Lansing, Michigan.

per machine (in italic type), and percent (of elapsed time) operator idle time (in non italic type), in randomly serviced multimachine assignments tended by one operator, when servicing demands are random and approximately the same for each assigned machine.

Random Machine Interference

Direct Measurement

Considerable effort has been spent in direct measurement of random machine interference, mainly via stop watch study. However, because of difficulties encountered in timing simultaneous events, rating the operator, and the like, the random machine interference table [9] is used. The mathematics on which this table is based could be understood by considering how four looms are assigned to one operator. Each loom is weaving the same type and size of fabric. Time study showed that this product would require, on an average, one minute of serving for each 6 minutes of elapsed time if the operator were to tend only one loom from a point of average walking distance, when four such looms are tended by a single operator. Thus the operator's work load (on an individual attention basis) for each of the four looms is 1/6 or 16.667% and the total work load is 4(1/6) or 66.67%. On rare occasions, all four or three of the four looms chance to become idle. When two or more looms are idle simultaneously, all but one being serviced must incur interference idleness. And as the operator subsequently services these looms, still others may demand servicing and therefore incur machine interference idleness. The average interference per loom could be estimated by using Table 6 by locating four machines in the left vertical column (no. machines), and reading to the 65 and 70 percent columns for (operator's total work load on individual attention bases) direct interpolation of the italicized 5.8% and 6.9% values to estimate the value of 66.7% load gives 6.2% average interference per machine (loom). In other words, on an average, for 100 minutes of elapsed assignment time, each of the four looms will be idle 6.2 minutes because of machine (loom) interference.

The operator percent unavoidable idleness for the four looms assumed can be estimated from Table 6 by direct interpolation between the nonitalicized values of 39% and 35% shown below the italicized interference values for 65% and 70% loads, the value being 37.7% for 66.67% work load. Actually this value would be 37.5% had the non-italicized values been expressed to the nearest one one-hundredth per cent. That is, on an average, all four looms would be running together and the operator would therefore be idle 37.5 minutes per 100 minutes of ellapsed time of assignment.

An analysis, details of which are shown in the appendix, was made to determine the effects of loom interference on lost production and how this interference time should be considered when assigning looms to weavers. The following procedure was carried out to calculate the optimal loom assignment per weaver.

Definitions of the Terms Used in the Analysis

W = number of weavers required

N = number of looms per weaver

N_t = total number of looms in production, (N_t = 250 looms)

T_i = interference time per loom per week

T_s = service time per loom per week

Fabric (i) : T_s = 41.60 minutes

Fabric (ii): T_s = 52.05 minutes

C_i = cost of lost pay per week, (variable)

C_p = cost of lost profit per week

C_w = cost of weavers per week

C_t = total cost per week

A = average percent interference per loom, (interpolated from Table 6)

B = percent work load of the weaver

PPM = speed of the loom in picks per minute

R = rate per 100,000 picks, (R = $0.4100)

P = cost of lost profit per hour

Fabric (i) : P = $0.30

Fabric (ii): P = $0.34

E = total pay per extra picks per week at a 100% loom efficiency

Base pay per weaver per hour = $2.50

The following equations were used to determine the minimum cost at which an optimal loom assignment is obtained:

$$B = \frac{T_s \times N}{40 \times 60}$$

where

40 is the number of hours per week

60 is the number of minutes per hour

$$T_i = \frac{A \times 40 \times 60}{100{,}000}$$

where 100,000 is the number of picks on which the incentive is based.

$$C_i = \frac{T_i \times PPM \times N_t \times R}{100{,}000}$$

$$C_p = \frac{T_t \times N_t \times P}{60}$$

$$E = \frac{PPM \times 40 \times 60 \times N_t \times R}{100{,}000}$$

$$C_w = (E - C_i) + \text{weavers base pay per week}$$

$$C_t = C_w + C_p$$

The results of this analysis are shown in Table 7 for fabric (i), and in Table 8 for fabric (ii).

Table 7. Comparison of Costs at Different Loom Assignments, Fabric (i)

W	N	B	T_i	T_s	T_t	C_i	C_p	C_w	C_t
3.6	69	120%	396.00	41.60	437.60	$ 384.12	$547.00	$ 746.12	$1293.12
4	63	108%	165.60	41.60	207.20	$ 428.28	$259.00	$ 828.28	$1087.28
5	50	87%	52.80	41.60	94.40	$ 449.90	$118.00	$ 949.90	$1067.90
6	40	69%	27.60	41.60	69.20	$ 454.73	$ 86.50	$1054.73	$1141.23
7	38	66%	26.16	41.60	67.76	$1070.31	$ 84.70	$1155.01	$1239.71

The final column of Table 7 indicates that having just 5 weavers, each assigned to 50 looms in fabric (i), is the best choice. The cost of this assignment is minimum compared to the costs of the other assignments in the same column. This is illustrated in Figure 3.

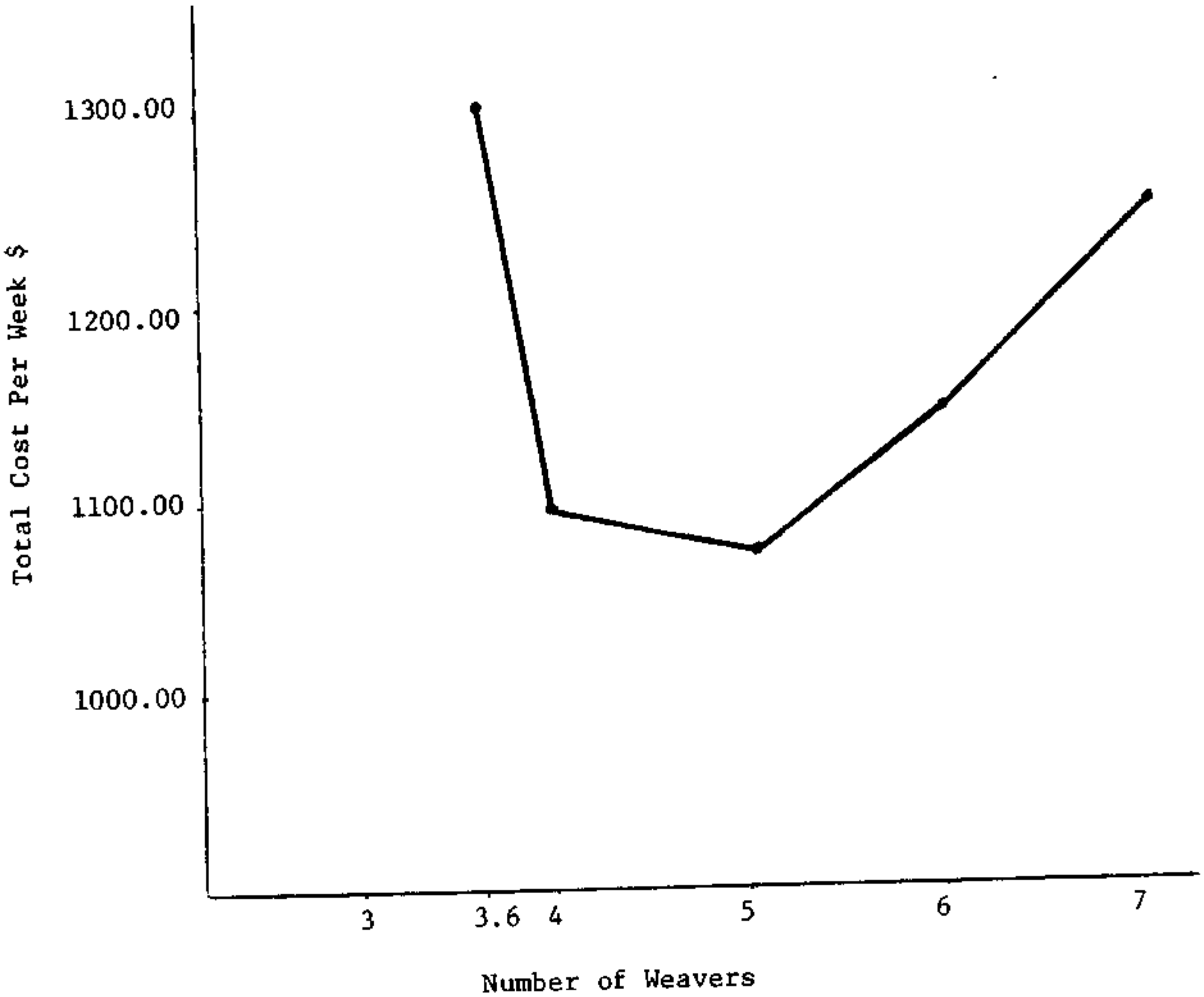

Figure 3. Total Cost vs. the Number of Weavers

Table 8. Comparison of Costs at Different Loom Assignments, Fabric (ii)

W	N	B	T_i	T_s	T_t	C_i	C_p	C_w	C_t
5	50	108%	187.20	52.05	239.25	$35.88	$338.94	$ 924.14	$1263.08
6	40	87%	64.80	52.05	116.85	$12.42	$165.54	$1047.60	$1213.14
7	38	82%	45.60	52.05	97.65	$ 8.74	$138.34	$1151.28	$1289.62
8	31	67%	31.20	52.05	83.25	$ 5.98	$117.94	$1254.04	$1371.98

The final column of Table 8 indicates that having just 6 weavers, each assigned to 40 looms, is the best choice. The cost of this assignment is minimum compared to the costs of other assignments in the same column. This is illustrated in Figure 4.

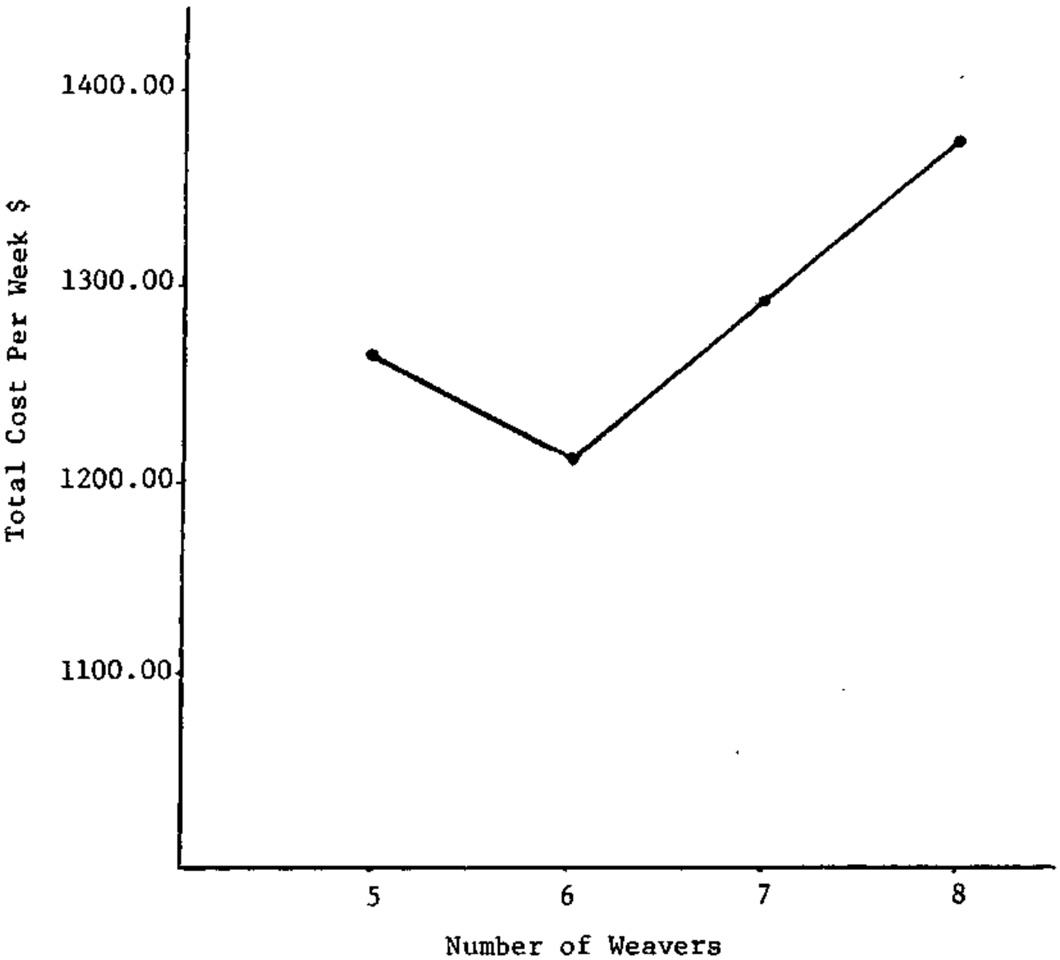

Figure 4. Total Cost vs. the Number of Weavers

CHAPTER V

CASE III: QUEUING MODEL

As it has been shown in Case II, the interference time has a substantial effect on loom assignment, and consequently, on costs of lost production. Case III attempts to illustrate a method of how the cost of waiting time could be measured by finding the average number of looms waiting for service. The first assumption to be made is that the arrivals for service (that is, various problems requiring service) are random and distributed according to the Poisson distribution, while time required to perform the services is exponentially distributed. The second assumption is that looms are served on first-come, first-serve basis, although this may not be followed exactly in actual practice by the weavers.

The total number of looms in the population is 500 looms, 250 looms for each fabric. This number is limited, therefore this problem is a finite queuing problem that could be solved by using "Finite Queuing Tables" [10].

The approach to this problem is to compare costs due to loom downtime (either waiting in line or being serviced), and the cost of a certain number of weavers, to the cost of the loom downtime when extra number of weavers is added. This is done by finding the average number of looms that are in the service system and multiplying this number by the cost of loom downtime per week. The cost of the weavers must be added [11] to the cost of the loom downtime to determine the total cost.

Definition of the Terms Used in the Model

N = the number of the looms in the population

W = the number of weavers

T = the time required to service the loom

U = the average time a loom runs before requiring service

X = the service factor, or proportion of service time required for each loom

$$X = \frac{T}{T+U}$$

L = the average number of looms waiting in line to be serviced

H = the average number of looms being serviced

D = the probability that a loom needing service will have to wait

F = the efficiency factor, which is a measure of the effect of having to wait in line to be serviced

Calculation of the Values of T, U, and X, Fabric (i)

From data shown in Table 3, in Case I, the time required to service the loom could be expressed as follows:

$$T = \frac{0.995 + 0.665 + 0.405}{3}$$

$$= 0.685 \text{ minutes}$$

The number of stops per loom per week (40 hours), is:

$$= 11.20 + 36.80 + 8.40$$

$$= 56.40$$

The average time a loom runs before requiring a service is:

$$U = \frac{40 \text{ loom hours}}{56.40 \text{ stops per 40 hours}}$$

$$= 0.709 \text{ hours}$$

$$= 0.709 \times 60 = 42.54 \text{ minutes}$$

The service factor

$$X = \frac{T}{T+U}$$

$$X = \frac{0.685}{0.685 + 42.54}$$

$$X = 0.0158$$

$$X = 0.016$$

From finite queuing tables, the following values for D (the probability of a loom needing a service will have to wait), and F (the efficiency factor) were obtained. Using equations:

$$L = N(1-F)$$

and

$$H = N F X$$

Table 9. Values of D and F, Fabric (i)

W	X	D	F
3	0.016	0.930	0.900
4	0.016	0.897	0.956
5	0.016	0.533	0.993
6	0.016	0.275	0.998
7	0.016	0.130	0.999
8	0.016	0.050	0.999

Table 10 was constructed where L, H, F, N, and X are as defined before. Table 10 shows the average number of looms waiting in line to be serviced (L), and the average of looms being serviced (H).

Calculation of the Total Cost Per Week, Fabric (i)

N = 250 looms

PPM = picks per minute (PPM = 187)

Number of hours per week = 40

Base pay per weaver per hour = \$2.50

Rate per 100,000 picks = \$0.4100

Lost profit per loom per week = \$0.30 x 40 = \$12.00

Using the following equation, the variable cost C_v at different loom assignments was obtained.

$$C_v = \frac{[N - (H + L)] \times PPM \times 40 \times 60 \times \$0.4100}{100{,}000}$$

Assuming that only output is lost, without prepercusions on sales, dealer relations, or the like. Table 11 shows a comparison of the total cost C_t per week, when different numbers of weavers are used.

The final column of Table 11 indicates that having just 4 weavers to take care of 250 looms is the best choice, and it represents the optimal loom assignment for fabric (i). The cost of this assignment is minimum as it is illustrated in Figure 5.

The 250 looms may be assigned to these 4 weavers as 63 looms per weaver.

Table 10. Values of L and H, Fabric (i)

W	L	H
3	25.00	3.60
4	11.00	3.82
5	1.75	3.97
6	0.50	3.99
7	0.25	4.00
8	0.25	4.00

Table 11. Comparison of Loom Downtime and Repair Costs, Fabric (i)

No. of weavers W	No. of looms down (H+L)	Cost of looms down per week (H+L) x $12.00	Variable cost per week C_v	Cost of weavers per week ($2.50/hr. each)	Total cost per week C_t
3	28.60	$343.20	$407.39	$ 707.39	$1050.59
4	14.82	177.84	432.75	832.75	1010.59
5	5.72	68.64	449.49	949.49	1018.13
6	4.49	53.88	451.76	1051.76	1105.64
7	4.25	51.00	452.20	1152.20	1203.20
8	4.25	51.00	452.20	1252.20	1303.20

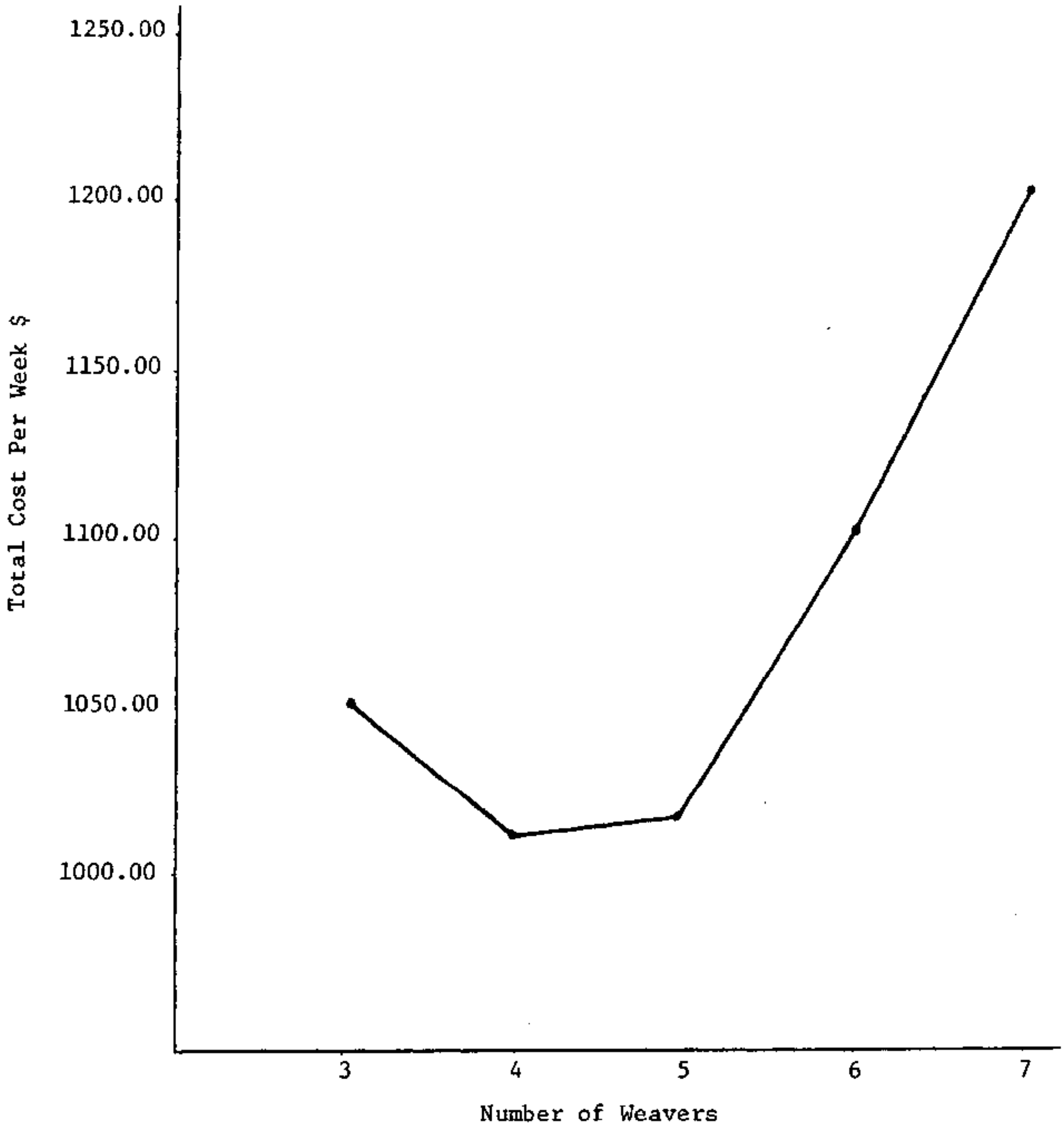

Figure 5. Total Cost vs. the Number of Weavers

Calculation of the Values of T, U, and X, Fabric (ii)

From data shown in Table 5, in Case I, the time required to service the loom could be expressed as follows:

$$T = \frac{0.995 + 0.655 + 0.405}{3}$$

$$T = 0.685 \text{ minutes}$$

The number of stops per loom per week (40 hours), is

$$= 15.18 + 44.50 + 10.03$$

$$= 69.71$$

The average time a loom runs before requiring service is

$$U = \frac{40 \text{ loom hours}}{69.71 \text{ stops/40 hrs.}}$$

$$U = 0.57 \text{ hours}$$

$$U = 0.57 \times 60 = 34.43 \text{ minutes}$$

The service factor,

$$X = \frac{0.685}{0.685 + 34.43}$$

$$X = 0.0195$$

$$X = 0.020$$

Again from finite queuing tables, the following values of D and F are obtained (see Table 12).

Using the same equations for L and H, as stated before in fabric (i), Table 13 was constructed. Table 13 shows the average number of looms waiting in line for service and the average number of looms being serviced.

Calculation of the Total Cost Per Week, Fabric (ii)

N = 250 looms

PPM = picks per minute (PPM = 187)

Number of hours per week = 40

Base pay per weaver per hour = \$2.50

Rate per 100,000 picks = \$0.4100

Lost profit per loom per week = \$0.34 x 40 = \$13.60

Using the following equation, the variable cost C_v at different loom assignments was obtained.

$$C_v = \frac{[N - (H + L)] \times PPM \times 40 \times 60 \times \$0.4100}{100{,}000}$$

Assuming that only output is lost, without prepercusions on sales, dealer relations, or the like. Table 14 shows a comparison of the total cost C_t per week, when different numbers of weavers are used. The final column of Table 14 indicates that having just 5 weavers, each assigned to 50 looms, is the best choice since this assignment gives the minimum cost as compared to the costs of the other assignments in the same column. This is illustrated in Figure 6.

Table 12. Values of D and F, Fabric (ii)

W	X	D	F
4	0.020	0.895	0.910
5	0.020	0.885	0.957
6	0.020	0.559	0.991
7	0.020	0.311	0.997
8	0.020	0.160	0.999

Table 13. Values of L and H, Fabric (ii)

W	L	H
4	22.50	4.55
5	10.75	4.79
6	2.25	4.96
7	0.75	4.99
8	0.25	5.00

Table 14. Comparison of Loom Downtime and Repair Costs for Fabric (ii)

No. of weavers W	No. of looms down (H+L)	Cost of looms down per week (H+L) x $13.60	Variable cost per week C_v	Cost of weavers per week ($2.50/hr. each)	Total cost per week C_t
4	27.05	$367.88	$410.25	$ 810.25	$1178.13
5	15.54	211.34	431.43	931.43	1142.77
6	7.21	98.06	446.75	1046.75	1144.81
7	5.74	78.06	449.46	1149.46	1227.52
8	5.25	71.40	450.36	1250.36	1321.76

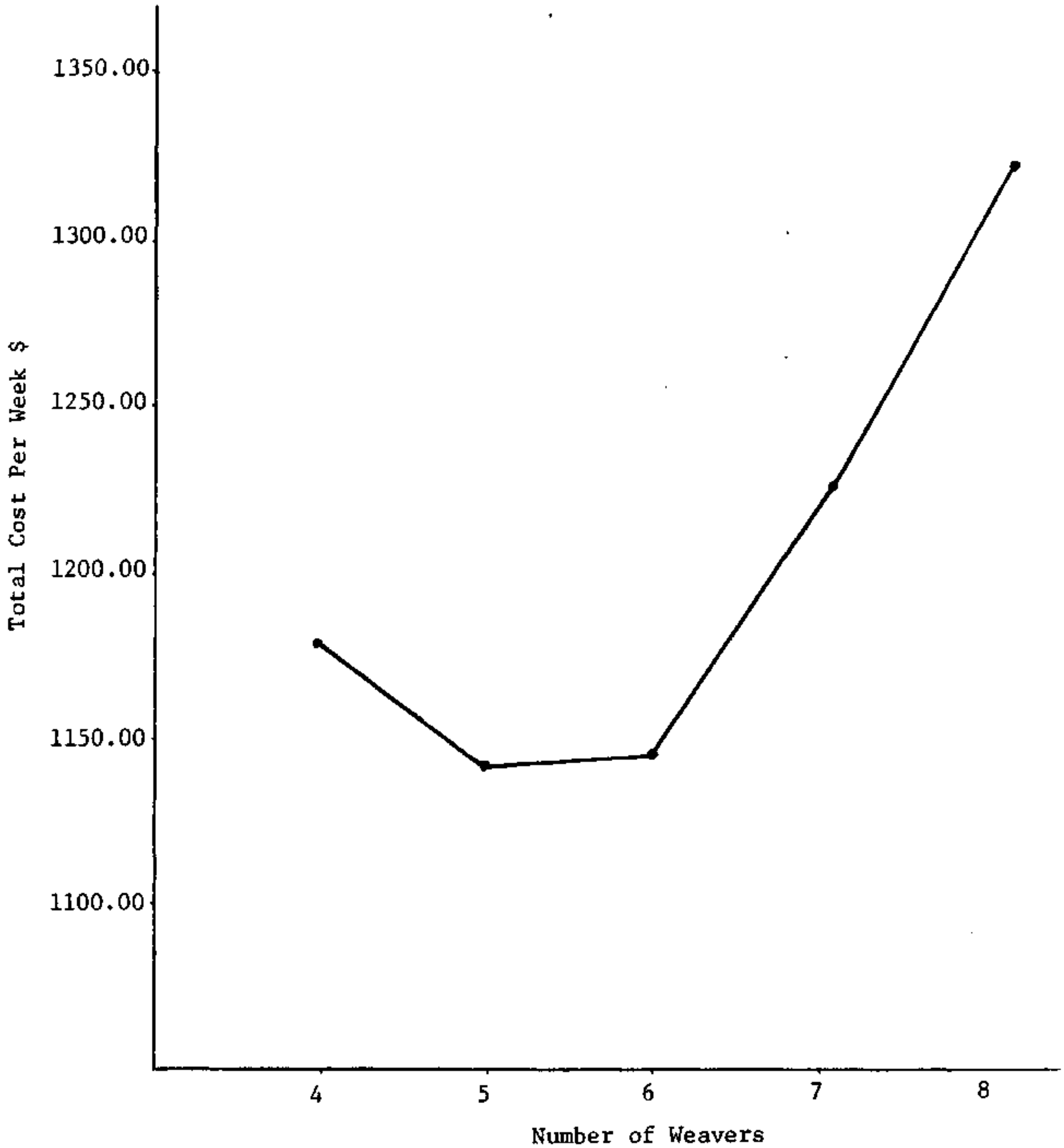

Figure 6. Total Cost vs. the Number of Weavers

CHAPTER VI

COMPARISON OF CASES I, II, AND III

By looking at the Cases I, II, and III discussed earlier in this study, it can be seen that:

In Case I, the traditional method of loom assignment, which is used by most weaving mills in the textile industry, the number of looms assigned to a weaver is a function of the rate of loom stoppages. The more stoppages the looms have, the more downtime of the loom will occur; and hence, more weavers are required. This method does not consider the loom interference time. The weaver is given a maximum load to keep him utilized as much as possible, based on the frequency of loom stops that may be incurred. Table 15 indicates that for Case I 36 looms per weaver is considered as an optimal assignment for fabric (i), and 31 looms per weaver on the average for fabric (ii), where 7 and 8 weavers are required respectively.

In Case II, Table 7 indicates that in fabric (i), as the number of looms N per weaver increases, the interference time T_i increases. The total cost C_t per week decreases as the number of looms pwer weaver increases. This is due to the decrease in the number of weavers required. Table 7 indicates that for fabric (i) it is better to have 5 weavers each assigned 50 looms because this assignment gives a minimum cost as shown in Figure 3.

Table 8 indicates that for fabric (ii), the best choice is to have

Table 15. Comparison of Cases I, II, and III

	CASE I		CASE II		CASE III	
	Fabric (i)	Fabric (ii)	Fabric (i)	Fabric (ii)	Fabric (i)	Fabric (ii)
Number of weavers required	7	8	5	6	4	5
Average no. of looms per weaver	36	31	50	42	63	50
Cost of lost production per week $	51.90	73.00	118.00	165.54	177.84	211.34
Cost of weavers per week $	1152.05	1250.04	949.90	1047.60	832.75	931.48
Total cost per week $	1203.96	1323.04	1067.90	1213.14	1010.59	1142.77

6 weavers, each assigned to 42 looms on the average. The cost of this assignment is minimum compared to the cost of other assignments in the same table. In other words, when less than 6 weavers are utilized, the loom waiting time will increase, and consequently the cost will increase causing an increase in the the total cost. If more than 6 weavers are utilized, the cost of the weavers will increase causing an increase in the total cost. Figure 4 illustrates how the costs are minimum when 6 weavers are utilized.

In Case III, where a queuing model is used, Table 11 indicates that having just 4 weavers for fabric (i) is the best choice where each weaver is assigned to 63 looms on the average. The cost of this assignment is minimum. Figure 5 is a plot of the weaving costs for various numbers of weavers.

Table 14 indicates that having just 5 weavers for fabric (ii) is the best choice where each weaver is assigned to 50 looms. The cost of this assignment is minimum as shown in Figure 6.

Table 15 is a summary of the results of the three cases.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

When this thesis study was begun it became evident that there was a lack of historical data relating to the topic. The general loom assignment method (Case I) carried out in most weaving mills omitted the consideration of loom interference time. This study discussed a method of how loom interference can affect the loom efficiency. The results of the application of this method indicated that the effect of loom interference on lost production is substantial and should be considered when assigning looms to weavers.

Most weaving mills try to allocate sufficient looms to weavers to ensure that the work load of the weaver is 100% and that he is fully utilized. They usually try to eliminate the unoccupied time of the weaver and do not place sufficient emphasis on the loom efficiency and its effect on the cost of loom output.

The effect of loom interference is reduced when the weaver tends less than the number of looms that would give him a full work load. This reduction of loom interference causes the loom efficiency to increase. If the work load is so reduced, a higher number of weavers is required causing an increase in the cost of labor. An increase in the production level due to the increase in the loom efficiency will result, however. Although there will be an increase in the labor cost due to the increase in the number of weavers required, there consequently can result a decrease in the total cost which includes the cost of lost production.

For the cost data used, Cases II and III of this study indicated that giving the weaver a higher work load will be more economical. This approach reduces the number of weavers, which consequently reduces the total cost, provided the reduction in the number of weavers will not exceed the limit where the downtime of the loom will be so high as to offset the savings made by reducing the number of weavers. This is shown in Figures 3, 4, 5, and 6, where a balance between achieving a maximum utilization of looms and labor while trying to achieve a minimum cost per unit of output is necessary.

Recommendations

Since only one set of economic data and one kind of argument for measurement of the cost of lost production exist, the results of this study may not be applicable to all weave room situations.

It is recommended that the information obtained in this study be used as a guide for more complete investigation of the problems of loom assignment. The first step in such an investigation would be to extend the study to a broader range of service times and loom stoppage rate. With the variability of these factors, more reliable data could be generated for more conclusive comparison of the results. The second step is the inclusion of the fixed cost factor, which this study did not take into account. By doing this, different results may be obtained.

APPENDIX

Calculation of the Total Cost Per Week, Fabric (i)

Number of looms per weaver:	69
Work load per weaver:	120%
Number of weavers required:	3.62
Incentive per 100,000 picks:	\$0.4100
Base pay per weaver per hour:	\$2.50
Base pay of weavers per week:	\$362.00

From Table 6, at N=69 looms per weaver, and at 120% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{16.5 \times 40 \times 60}{100}$$

$$T_i = 396.00 \text{ minutes}$$

From Table 3, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 41.60 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 437.60 \text{ minutes}$$

The cost of lost production due to loom interference time per week, (lost pay), is

$$C_i = \frac{396.00 \times 187 \times 250 \times \$0.4100}{100,00}$$

$$C_i = \$75.90$$

Cost of lost profit per week is

$$C_p = \frac{437.60 \times 250 \times \$0.30}{60}$$

$$C_p = \$547.00$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100,000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$746.12$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1293.12$$

Calculation of the Total Cost Per Week, Fabric (i)

Number of looms per weaver:	63
Work load per weaver:	108%
Number of weavers required:	4
Incentive per 100,000 picks:	$0.4100
Base pay per weaver per hour:	$2.50
Base pay of weavers per week:	$400.00

From Table 6, at N=63 looms per weaver, and at 108% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{6.9 \times 40 \times 60}{100}$$

$$T_i = 165.60 \text{ minutes}$$

From Table 3, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 41.60 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 207.20 \text{ minutes}$$

The cost of lost production due to loom interference time per week is

$$C_i = \frac{165.60 \times 187 \times 250 \times \$0.4100}{100,000}$$

$$C_i = \$31.74$$

Cost of lost profit per week is

$$C_p = \frac{207.20 \times 250 \times \$0.30}{60}$$

$$C_p = \$259.00$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100,000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$828.28$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1087.28$$

Calculation of the Total Cost Per Week, Fabric (i)

Number of looms per weaver:	50
Work load per weaver:	87%
Number of weavers required:	5
Incentive per 100,000 picks:	$0.4100
Base pay per weaver per hour:	$2.50
Base pay of weavers per week:	$500.00

From Table 6, at N=50 looms per weaver, and at 87% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{2.2 \times 40 \times 60}{100}$$

$$T_i = 52.80 \text{ minutes}$$

From Table 3, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 41.60 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 94.40 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{52.80 \times 187 \times 250 \times \$0.4100}{100,000}$$

$$C_i = \$10.12$$

Cost of lost profit per week is

$$C_p = \frac{94.40 \times 250 \times \$0.30}{60}$$

$$C_p = \$118.00$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100,000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$949.90$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1067.90$$

Calculation of the Total Cost Per Week, Fabric (i)

Number of looms per weaver:	40
Work load per weaver:	69%
Number of weavers required:	6
Incentive per 100,000 picks:	\$0.4100
Base pay per weaver per hour:	\$2.50
Base pay of weavers per week:	\$600.00

From Table 6, at N=40 looms per weaver, and at 69% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{1.15 \times 40 \times 60}{100}$$

$$T_i = 27.60 \text{ minutes}$$

From Table 3, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 41.60 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 69.20 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{27.60 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$5.29$$

Cost of lost profit per week is

$$C_p = \frac{69.20 \times 250 \times \$0.30}{60}$$

$$C_p = \$86.50$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$1054.73$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1141.23$$

<u>Calculation of the Total Cost Per Week, Fabric (i)</u>

Number of looms per weaver:	38
Work load per weaver:	66%
Number of weavers required:	7
Incentive per 100,000 picks:	$0.4100
Base pay per weaver per hour:	$2.50
Base pay of weavers per week:	$700.00

From Table 6, at N=38 looms per weaver, and at 66% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{1.09 \times 40 \times 60}{100}$$

$$T_i = 26.16 \text{ minutes}$$

From Table 3, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 41.60$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 67.76 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{26.16 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$5.01$$

Cost of lost profit per week is

$$C_p = \frac{67.76 \times 250 \times \$0.30}{60}$$

$$C_p = \$84.70$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$1155.01$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1239.71$$

Calculation of the Total Cost Per Week, Fabric (ii)

Number of looms per weaver:	50
Work load per weaver:	108%
Number of weavers required:	5
Incentive per 100,000 picks:	\$0.4100
Base pay per weaver per hour:	\$2.50
Base pay of weavers per week:	\$500.00

From Table 6, at N=50 looms per weaver, and at 108% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{7.8 \times 40 \times 60}{100}$$

$$T_i = 187.20 \text{ minutes}$$

From Table 5, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 52.05 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 239.25 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{187.20 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$35.88$$

Cost of lost profit per week is

$$C_p = \frac{239.25 \times 250 \times \$0.34}{60}$$

$$C_p = \$338.94$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is:

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$924.14$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1263.08$$

Calculation of the Total Cost Per Week, Fabric (ii)

Number of looms per weaver:	40
Work load per weaver:	87%
Number of weavers required:	6
Incentive per 100,000 picks:	$0.4100
Base pay per weaver per hour:	$2.50
Base pay of weavers per week:	$600.00

From Table 6, at N=40 looms per weaver, and at 87% work load, the interference time per loom per week is calculated as follows:

$$T_i = \frac{2.7 \times 40 \times 60}{100}$$

$$T_i = 64.80 \text{ minutes}$$

From Table 5, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 52.05 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 116.85 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{64.80 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$12.42$$

Cost of lost profit per week is

$$C_p = \frac{116.85 \times 250 \times \$0.34}{60}$$

$$C_p = \$165.54$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows:

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$1047.60$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1213.14$$

Calculation of the Total Cost Per Week, Fabric (ii)

Number of looms per weaver:	38
Work load per weaver:	82%
Number of weavers required:	7
Incentive per 100,000 picks:	\$0.4100
Base pay per weaver per hour:	\$2.50
Base pay of weavers per week:	\$700.00

From Table 6, at N=38 looms per weaver, and at 82% work load, the interference time per loom per week is calculated as follows

$$T_i = \frac{1.90 \times 40 \times 60}{100}$$

$$T_i = 45.60 \text{ minutes}$$

From Table 5, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 52.05 \text{ minutes}$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 97.65 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{45.60 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$8.74$$

Cost of lost profit per week is

$$C_p = \frac{97.65 \times 250 \times \$0.34}{60}$$

$$C_p = \$138.34$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$1151.28$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1289.62$$

Calculation of the Total Cost Per Week, Fabric (ii)

Number of looms per weaver:	31
Work load per weaver:	67%
Number of weavers required:	8
Incentive per 100,000 picks:	\$0.4100
Base pay per weaver per hour:	\$2.50
Base pay of weavers per week:	\$800.00

From Table 6, at N=31 looms per weaver, and at 67% work load, the interference time per loom per week is calculated as follows

$$T_i = \frac{1.30 \times 40 \times 60}{100}$$

$$T_i = 31.20 \text{ minutes}$$

From Table 5, the total time a loom is out of production due to stoppage servicing time is

$$T_s = 52.05$$

The total time a loom may be out of production due to interference and servicing times is

$$T_t = 83.25 \text{ minutes}$$

The cost of lost production due to loom interference time per week (lost pay) is

$$C_i = \frac{31.20 \times 187 \times 250 \times \$0.4100}{100{,}000}$$

$$C_i = \$5.98$$

Cost of lost profit per week is

$$C_p = \frac{83.25 \times 250 \times \$0.34}{60}$$

$$C_p = \$117.94$$

The total cost of incentive pay per week at a 100% efficiency is calculated as follows

$$E = \frac{187 \times 40 \times 60 \times 250 \times \$0.4100}{100{,}000}$$

$$E = \$460.02$$

The total cost of weavers per week is

$$C_w = \text{Base pay per week} + (E - C_i)$$

$$C_w = \$1254.04$$

The total cost per week is

$$C_t = C_w + C_p$$

$$C_t = \$1371.98$$

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